CHAPTER 6

OPEN CHANNELS

6-1. General.

One of the most difficult problems associated with surface drainage facilities is the design of effective, stable, natural, open channels that will not be subject to severe erosion and/or deposition. Tests show that performance is poorer and requires more costly and more frequent maintenance to provide effective drainage channels. Open channels which meet the airfield and heliport's safety and operational requirements will be used since they provide greater flexibility, a higher safety factor, and are more cost effective. Drop structures and check dams can be used to control the effective channel gradient.

6-2. Channel design.

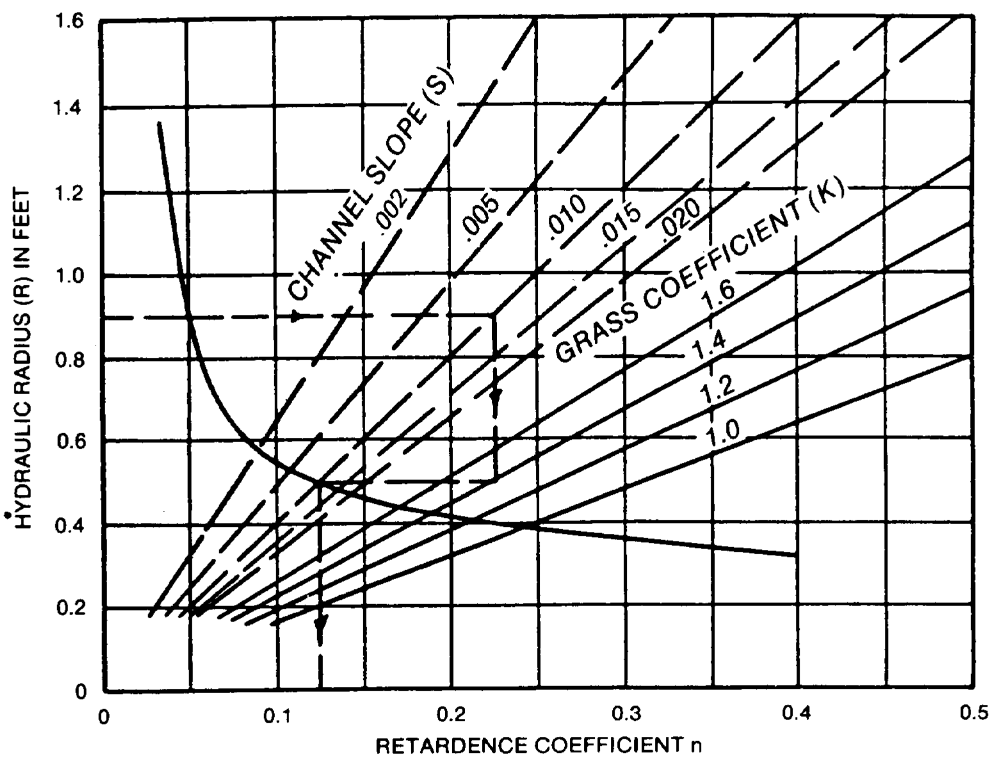
The following items merit special consideration in designing channels.

a. The hydraulic characteristics of the channel may be studied by using an open-channel formula such as Manning's. Suggested retardance coefficients and maximum permissible velocities for nonvegetated channels are given in table 6-1. Retardance coefficients for turf-lined channels are a function of both the turf characteristics and the depth and velocity of flow and can be estimated by the graphical relations shown in figure 6-1. It is suggested that maximum velocity in turf-lined channels not exceed 6 feet per second. In regions where runoff has appreciable silt load, particular care will be given to securing generally nonsilting velocities.

Table 6-1. Suggested coefficients of roughness and maximum permissible mean velocities for open channels in military construction.

Material	Manning's n	Maximum permissible mean velocity ft/sec
Concrete, with surfaces as indicated:		
Formed, no finish.	0.014	___
Trowel finish.	0.012	___
Float finish	0.012	___
Gunite, good section	0.016	30
Concrete, bottom float finish, sides as indicated:		
Cement rubble masonry.	0.020	20
Cement rubble masonry, plastered.	0.018	25
Rubble lined, uniform section . .	0.030-0.045	7-13
Asphalt:		
Smooth	0.012	15
Rough.	0.016	12
Earth, uniform section:		
Sandy silt, weathered.	0.020	2.0
Silt clay.	0.020	3.5
Soft shale	0.020	3.5
Clay	0.020	6.0
Soft sandstone	0.020	8.0
Gravelly soil, clean	0.025	6.0
Natural earth, with vegetation. .	0.03-0.150	6.0
Grass swales and ditches[1]		6.0

[1] See figure 6-1.



GRASS COEFFICIENTS (K) FOR DENSE AIRFIELD TURF

GRASS SPECIES	AVG LENGTH OF GRASS IN INCHES		
	<6	6-12	>12
BUFFALO	1.6	--	--
BLUE GRAMMA	1.5	1.4	1.3
BLUE GRASS	1.4	1.3	1.2
BERMUDA	1.4	1.3	1.2
LESPEDEZA SERICEA	1.3	1.2	1.1

EXAMPLE:

DETERMINE n FOR 4-INCH BERMUDA GRASS CHANNEL WITH R = 0.9 and S = 0.010.

FROM TABLE k = 1.4 AND FROM GRAPH, FOLLOWING DASHED LINE, n IS EQUAL TO 0.125.

Figure 6-1. Retardance coefficients for flow in turfed channels.

b. The selection of the channel cross section is predicted on several factors other than hydraulic elements. Within operational areas the adopted section will conform with the grading criteria contained in AFR 86-8 or TM 5-803-4. Proposed maintenance methods affect the selection of side slopes for turfed channels since gang mowers cannot be used on slopes steeper than 1 vertical (V) to 3 horizontal (H), and hand cutting is normally required on steeper slopes. In addition, a study will be made of other factors that might affect the stability of the side slopes, such as soil characteristics, excessive ground-water inflow, and bank erosion from local surface-water inflow.

c. Earth channels normally require some type of lining such as that obtained by developing a strong turf of a species not susceptible to rank growth. In particularly erosive soils, special methods will be necessary to establish the turf quickly or to provide supplemental protection by mulching or similar means. For further discussion of turfing methods, see TM 5-803-13/AFM 126-8. Where excessive velocities are to be encountered or where satisfactory turf cannot be established and maintained, it may be necessary to provide a paved channel.

d. A channel design calling for an abrupt change in the normal flow pattern induces turbulence and causes excessive loss of head, erosion, or deposition of silt. Such a condition may result at channel transitions, junctions, storm-drain outlets, and reaches of excessive curvature, and special attention will be given to the design of structures at these locations.

e. Channel design in appendix D must include measures for preventing uncontrolled inflow from drainage areas adjacent to open channels. This local inflow has caused numerous failures and is particularly detrimental where, due to the normal irregularities experienced in grading operations, runoff becomes concentrated and results in excessive erosion as it flows over the sides of the channel. A berm at the top edge of the channel will prevent inflow except at designated points, where inlets properly protected against erosion are provided. The inlet may vary from a sodded or paved chute to a standard field inlet with a storm drain connection to the channel. Erosion resulting from inflow into shallow drainage ditches or swales with flat side slopes can be controlled by a vigorous turfing program supplemented by mulching where required. Where excavated material is wasted in a levee or dike parallel and adjacent to the channel, provision will be made for frequent openings through the levee to permit local inflow access to the channel. A suitable berm (minimum of 3 feet) will be provided between the levee and the top edge of the channel to prevent sloughing as a result of the spoil bank load and to minimize movement of excavated material back into the channel. Example problems in channel design are shown in appendix D.

f. Field observations indicate that stable channels relatively free of deposition and/or erosion can be obtained provided the Froude number of flow in the channel is limited to a certain range depending upon the type of soil. An analysis of experimental data indicates that the Froude number of flow (based on average velocity and depth of flow) required to initiate transport of various diameters of cohesionless material, d_{50}, in a relatively wide channel can be predicted by the empirical relation, $F = 1.88\ (d_{50}/D)^{1/3}$. The terms are defined in appendix E.

6-3. Design procedure.

a. This design procedure is based on the premise that the above empirical relation can be used to determine the Froude number of flow in the channel required to initiate or prevent movement of various sizes of material. Relations based on the Manning formula can then be applied to determine the geometry and slope of a channel of practical proportion that will convey flows with Froude numbers within a desired range such that finer material will be transported to prevent deposition but larger material will not be transported to prevent erosion.

b. Appendix D contains an example problem for the design of a channel using this procedure. It will satisfy the conditions desired for the design discharge and one that will ensure ho deposition or erosion under these conditions.

6-4. Drop structures and check dams.

a. Drop structures and check dams are designed to check channel erosion by controlling the effective gradient and to provide for abrupt changes in channel gradient by means of a vertical drop. They also provide satisfactory means for discharging accumulated surface runoff over fills with heights not exceeding 5 feet and over embankments higher than 5 feet if the end sill of the drop structure extends beyond the toe of the embankment. The check dam is a modification of the drop structure used for erosion control in small channels where a less elaborate structure is permissible.

b. There are numerous types of drop and grade control structures. They can be constructed of concrete, metal piling, gabions, riprap, or a combination of materials. Design of many of these structures is beyond the scope of this manual, and if the designer needs design information for a specific type structure, the publications in the bibliography should be consulted.

c. Pertinent features of a typical drop structure are shown in figure 6-2. The hydraulic design of these structures can be divided into two general phases: design of the weir and design of the stilling basin. It is emphasized that for a drop structure or check dam to be permanently and completely successful, the structure must be soundly designed to withstand soil and hydrostatic pressures and the effects of frost action, when necessary. Also, the adjacent ditches or channels must be completely stable. A stable grade for the channel must first be ascertained before the height and spacing of the various drop structures can be determined.

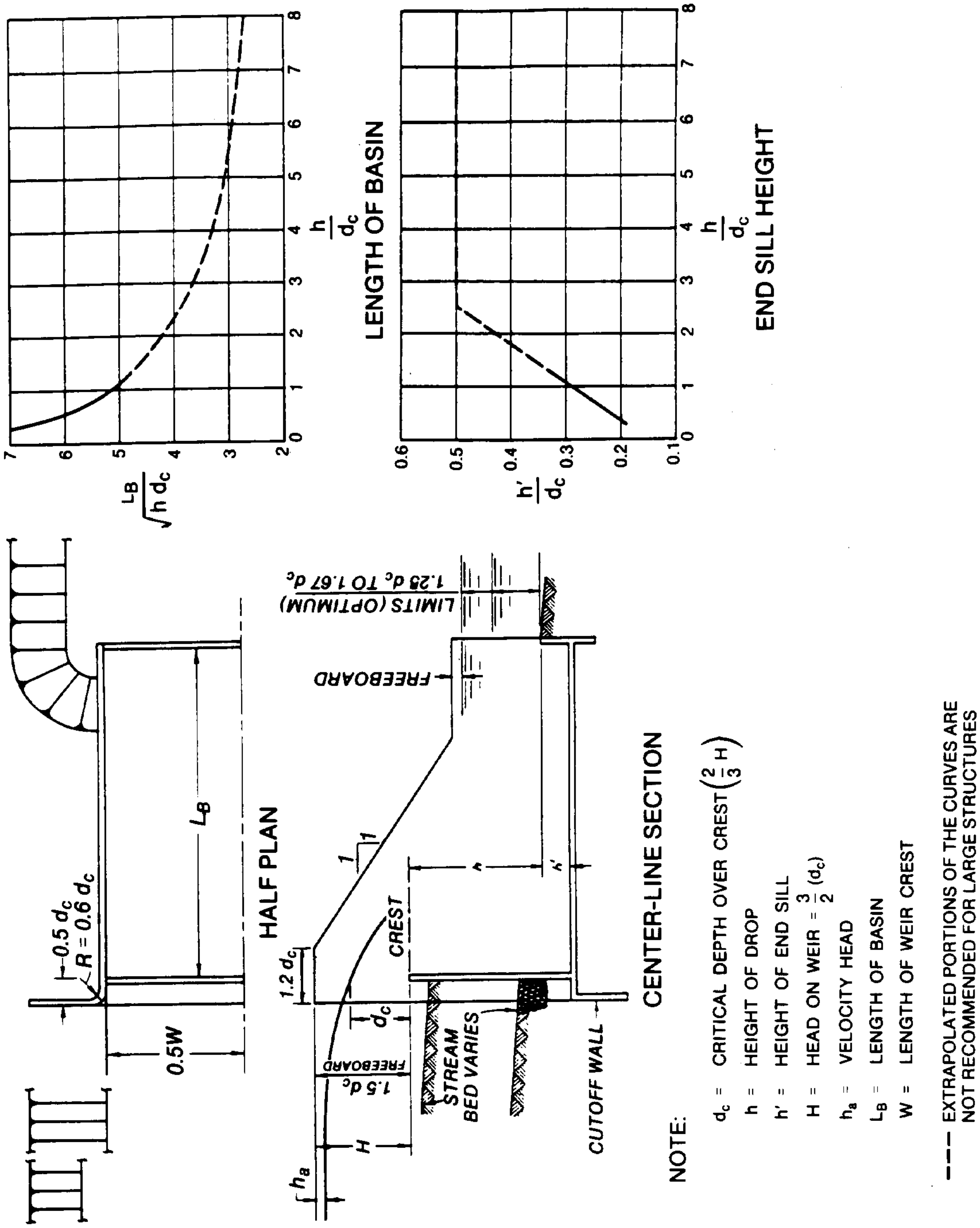


Figure 6-2. Details and design chart for typical drop structure.

d. The following design rules are based on hydraulic considerations only. They are minimum standards subject to increase on the basis of other considerations such as structural requirements and special frost condition design.

(1) Discharge over the weir should be computed from the equation $Q = CWH^{3/2}$ using a C value of 3.0. To minimize erosion and obtain maximum use of the available channel cross section upstream from the structure, the length of the weir should be adjusted to maintain a head on the weir equivalent to the depth of flow in the channel. A trial-and-error procedure should be used to balance the crest height and width with the channel cross section.

(2) The relation between the height of drop, h, critical depth at the drop, d_c, and the required stilling basin length, L_B, is defined by the equation

$$L_B = C_L\sqrt{hd_c} \quad \text{(eq 6-1)}$$

where C_L is an empirical coefficient between 2 and 7, as shown in figure 6-2. The stilling basin length and end sill height can be determined from the design curves in figure 6-2. Optimum performance of the basin is obtained when the tailwater-critical depth ratio is 1.25 to 1.67. However, the basin will function satisfactorily with higher tailwaters if the depth of tailwater above the weir does not exceed 0.7 d_c. The stilling basin walls should be high enough to prevent the tailwater from reforming over the walls into the stilling basin. Riprap protection should be provided immediately downstream from the structure. Guidance provided in paragraph 5-4*k* can be used for design of the riprap.

e. A design illustrating the use of the above information and figure 6-2 is shown in the following example. Design a drop structure for a discharge of 250 cubic feet per second in a trapezoidal channel with a 10-foot base width and side slopes of IV on 3H, and a depth of flow of 5 feet. The amount of drop required is 4 feet. If the crest is placed at invert of the channel, the head on the crest, H, will be equal to the depth of flow, 5 feet.

Width of Crest, W:

$$Q = CWH^{3/2} \quad \text{(eq 6-2)}$$

$$W = \frac{250}{3\times(5)^{3/2}} \; 7.5 \text{ feet} \quad \text{(eq 6-3)}$$

Since the base width of the channel is 10 feet, the weir crest should be made 10 feet long and raised up to maintain a depth of 5 feet upstream. If the width determined above would have been greater than 10 feet then the greater width would have had to be retained and the channel expanded to accommodate this width.

f. With width of crest equal to 10 feet determine head on the crest:

$$Q = CWH^{3/2} \quad \text{(eq 6-4)}$$

$$H = (250/3\times10)^{2/3} = 4.1 \text{ feet} \quad \text{(eq 6-5)}$$

Thus, crest elevation will be 5-4.1 = 0.9 feet above channel invert and distance from crest to downstreams channel invert, h , will be 4+0.9=4.9 feet.

Critical depth, d_c:

$$d_c = \frac{2}{3}H = \frac{2}{3}(4.1) = 2.73 \text{ feet} \quad \text{(eq 6-6)}$$

$$\frac{h}{d_c} = \frac{4.9}{2.73} = 1.8 \quad \text{(eq 6-7)}$$

From figure 6-2:

$$\frac{L_B}{\sqrt{hd_c}} = 4.4 \quad \text{(eq 6-8)}$$

$$L_B = 16.09 \text{ feet (use 16.1 feet)} \quad \text{(eq 6-9)}$$

$$\frac{h'}{d_c} = 0.4 \quad \text{(eq 6-10)}$$

$$h' = 0.4\times2.73 = 1.09 \text{ feet (use 1.1 feet)} \quad \text{(eq 6-11)}$$

The tailwater depth will depend on the channel configuration and slope downstream from the structure. If these parameters are the same as those of the approach channel, the depth of tail-water will be 5 feet. Thus, the tailwater/dc ratio is 5/2.73 = 1.83 which is greater than 1.67 recommended for optimum energy dissipation. However, the tailwater depth above the crest (5.0- .49 = 0.10) divided by critical depth (2.73) is (0.1/2.73=0.04) much less than 0.7 and the basin will function satisfactorily.

Riprap design:

$$d_{50} = D\left(\frac{V}{\sqrt{gD}}\right)^3 \quad \text{(eq 6-12)}$$

$$d_{50} = 5\left(\frac{5}{\sqrt{32.2 \times 5}}\right)^3 = 0.306 \text{ feet (use 4 inches)} \qquad \text{(eq 6-13)}$$

Riprap should extend approximately 10 times depth of flow downstream from structure (10 × 5 = 50 feet).

V = Discharge/area at end of basin = 250/ 10 × 5 = 5 feet per second